High-speed polarization multiplexed optical scanner for three-dimensional scanning applications

Khan, Sajjad, Riza, Nabeel

Sajjad A. Khan, Nabeel Agha Riza, "High-speed polarization multiplexed optical scanner for three-dimensional scanning applications," Proc. SPIE 5160, Free-Space Laser Communication and Active Laser Illumination III, (27 January 2004); doi: 10.1117/12.501352

Event: Optical Science and Technology, SPIE's 48th Annual Meeting, 2003, San Diego, California, United States

High Speed Polarization Multiplexed Optical Scanner for Three Dimensional Scanning Applications

Sajjad A. Khan and Nabeel A. Riza

Photonic Information Processing Systems Laboratory
The School of Optics/Center for Research and Education in Optics and Lasers (CREOL)
University of Central Florida, 4000 Central Florida Blvd., Orlando, FL 32816-2700
Tel: 407-823-6829; Fax: 407-823-6880; E-mail: nriza@mail.ucf.edu

ABSTRACT

A versatile high speed 3-D scanner design is proposed and demonstrated for optical beamforming applications such as free-space laser communications, 3-D displays, scanning 3-D optical microscopy, data retrieval, and vision applications. The scanner consists of fast digital-analog control polarization-based optical beamforming cells resulting in complete three-dimensional beamforming programmability. Features include low electrical power consumption and large aperture beamforming optics, digital repeatability, and time multiplexed accurate analog beamforming. Analog frequency and amplitude control of the nematic liquid crystal beamformer cells allows continuous fine scan programmability over a 0.66 mrad horizontal-deflection, 0.75 mrad vertical deflection, and an infinity to 1.84 m focal length longitudinal scan, all at 1310nm. For the first time is demonstrated a coarse angular deflection of an 8-point linear 1-D scan at 1550 nm with a 35 μs random-access time.

Keywords: Optical Scanner, Beam Steering, Polarization Multiplexing, Liquid Crystals, Digital Scanner.

1. INTRODUCTION

Optical scanners have wide ranging applications such as free-space optical wireless, inter-satellites links, mobile military platforms, and 3-D displays. Each of these applications has a different set of requirements. For example, inter-satellite links need fine angular scanning tunability of the order of 1μrad yet high speed to keep track of the fast moving destination satellite. Mobile military platforms need the scan dynamic range to be $\pm 45^{o}$ with minimal and fixed random-access scan time. Previously one dimensional (1-D) and two dimensional (2-D) laser beam steering techniques have been proposed including using nematic liquid crystals (NLCs) [1], ferroelectric liquid crystals (FLCs) [2], optical microelectromechanical systems (MEMS) technology [3], ferroelectric electrooptic materials such as lead zirconate titanate [4,5], and fixed birefringent material prisms [6]. These scanners have been limited to 1-D and 2-D scans and were suited for large scan angles. Other limitations included high drive voltages, pixelation, and non-programmable birefringent plate designs. Hence, the need arises for a generic scanner that can provide a large scan dynamic range as well as fine scan tuning, all at the same high speed.

Recently, we proposed such a three dimensional (3-D) scanner that can solve the dilemma of obtaining large angular dynamic range with fine tunable programmability, along with the capability to address the third dimension; i.e., the ability to focus or defocus a beam of light along its direction of propagation [7]. We showed how large aperture, non-pixelated liquid crystal devices can be used to demonstrate a fully programmable high speed polarization based scanner. In this paper, we elaborate upon the concept of combined coarse-fine 3-D Polarization-Multiplexed Optical Scanner (P-MOS) for near continuous optical scanning. Basic system architecture is described and performance results for a coarse P-MOS are shown.

Free-Space Laser Communication and Active Laser Illumination III,
edited by David G. Voelz, Jennifer C. Ricklin, Proc. of SPIE Vol. 5160
(SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.501352

2. P-MOS DESIGN

The basic Polarization-Multiplexed Optical Scanner (P-MOS) manipulates the polarization of an incoming laser beam in a digital fashion to achieve 3-D scanning. Key elements of the P-MOS are a polarization control element and a polarization dependent beam steering element. For polarization control, we use fast response digitally controlled 90^o polarization switches (PSs). For coarse scanning, bulk birefringent material wedges are used whereas for fine scanning electrically controlled nematic liquid crystal wedges are realized. Figure 1 shows the block diagram of the proposed 3-D P-MOS that provides both highly repeatable fast random-access digital scans as well as finely tunable analog scans. Figure 2 shows the schematic of basic 1-D coarse-fine P-MOS unit. Previously, we have demonstrated nematic liquid crystal (NLC) based fine 3-D scans [7]. Hence, the focus of this paper is to describe the combined coarse-fine P-MOS.

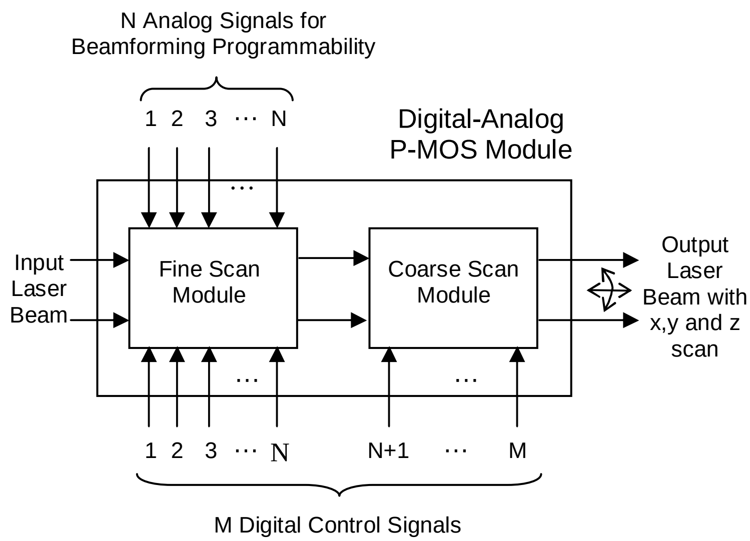

Fig.1: P-MOS Architecture.

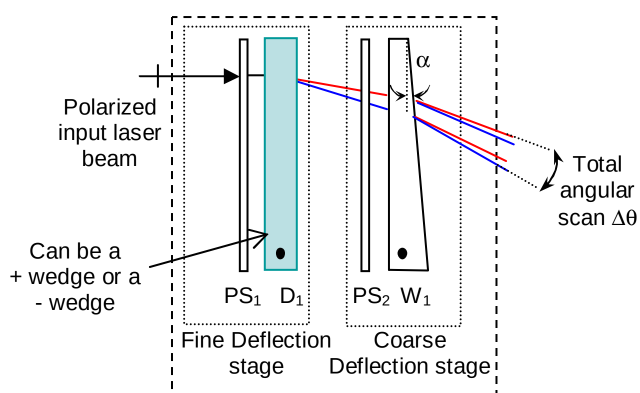

Fig. 2: 1-D coarse-fine module for optimal P-MOS design. PS: Polarization Switch, D: Deflector, W: Wedge.

In the P-MOS, one PS and one wedge combine to form one deflection stage. Several of these deflection stages can be cascaded to achieve a desired number of scan points in the far-field pattern. N such deflection stages result in 2^N deflection angles for the linearly polarized input laser beam. Moreover, two such 1-D stages can also be cascaded in orthogonal orientation to achieve a 2-D digital scanner. As opposed to scanners that use pixelated elements for beam scanning where some power is coupled into higher diffraction orders resulting in lower throughput efficiency, this design utilizes large-aperture pixel-free devices resulting in diffraction-free beam steering. These devices are made of birefringent materials so a laser beam will be steered into two different destinations depending upon the state of polarization of the incoming laser beam. In order to manipulate the laser beam position at a desired point in space, the polarization of the incident beam is controlled by using, for example, Ferro-electric Liquid Crystal (FLC) half-wave retarders. These FLC polarization switches have a fast response time (e.g. 35 μs @ 1310nm) and use simple two-level control voltages resulting in simple digital control electronics [8]. For the polarization dependent coarse beam scanning, bulk birefringent prisms are used for polarization dependent angular deflection. The birefringent material chosen for P-MOS design is Rutile (n_e=2.454, n_o=2.71 @ λ=1529.6nm). The orientation of the crystal c-axis is chosen such that at the entrance interface of the prism the following relation is satisfied:

$$n_{inc} \sin \theta_{inc} = n_o \sin \theta_o = n_e \sin \theta_e$$

where n_{inc} is the index of the material from which the beam enters the birefringent crystal, θ_{inc} is the angle of incidence, and θ_o and θ_e are the refracted angles inside the birefringent material as seen by the ordinary n_o and extra-ordinary n_e indices, respectively. Hence the input laser beam is steered into two different destinations depending upon its state of polarization. Successive application of this boundary condition will allow us to find out the exit angles from a birefringent prism. Figure 3 shows the design of a 3-stage coarse P-MOS using Rutile prisms. Hence, by the combined use of the coarse-fine hybrid control scan technique, one can essentially access any point in the total scan domain.

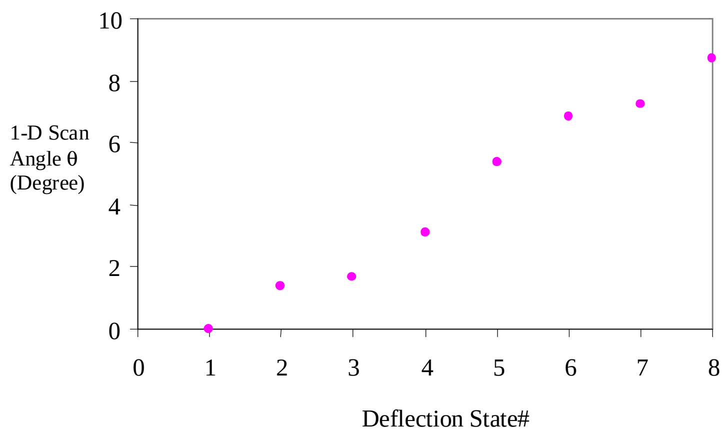

Fig. 3: Designed deflection angles for a 3-stage coarse 1-D P-MOS scanner. α_1= 4.95°, α_2= 14.95° and α_3= −4.95° using Rutile (n_e=2.454, n_o=2.71 @ λ=1529.6nm).

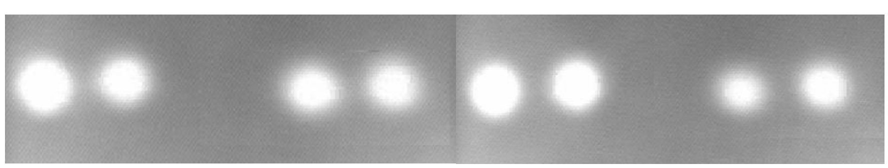

Fig. 4: Experimentally measured far-field spot pattern for 3-stage coarse digital P-MOS demonstration at 1550nm. Note that due to large angular separation, the picture of the spot pattern was taken in two separate frames.

3. EXPERIMENT

Figure 4 shows the resulting experimentally measured far-field spot pattern for the designed P-MOS. The average insertion loss for the FLC PS's was measured to be 1dB at 1550nm while their average optical polarization extinction ratio was 28dB. There are some issues that need to be thoroughly considered while choosing the birefringent crystals for use in the coarse digital P-MOS. Large index of refraction is desirable as it will result in thin angular wedges but then it requires anti-reflection coatings to reduce the Fresnel reflections from the wedge surfaces. Fresnel reflections are an important aspect to consider in such a cascaded design as they can cause high insertion losses for the proposed scanner. Moreover, one needs to make sure that the absorption coefficient of the material is small in the wavelength band of operation of the P-MOS. Also, higher birefringence will result in large walk-off angle. Walk-off angle is defined as the angular separation between the ordinary and the extra-ordinary ray at the exit face of the wedge. Note that because of the cascaded nature of the P-MOS, care must be taken to reduce voxel scan stages (e.g., ten) to keep losses minimal.

4. CONCLUSION

In summary, a coarse scanning module is demonstrated based on our earlier proposed versatile high speed P-MOS scanner design that is well suited for optical beamforming applications such as laser communications, 3-D displays, scanning 3-D optical microscopy, data retrieval, and vision applications. For the first time, the coarse scanning aspect of the P-MOS module is experimentally demonstrated via an eight point 1-D linear scan at 1550 nm with a 35 μs random-access time. Future work relates to demonstration of large scan dynamic range and finely tunable coarse-fine P-MOS.

Acknowledgment

The authors would like to acknowledge DARPA STAB program for supporting this research work.

References

1. A. F. Fray and D. Jones, "Liquid crystal light deflector", U.S. Patent 4066334, 1978.
2. B. Lofving and S. Hard, "Beam steering with two ferroelectric liquid-crystal spatial light modulators", Opt. Lett., **23**, 19, 1541-1543, 1998.
3. M. H. Kiang, O. Solgaard, K. Y. Lau and R. S. Muller, "Electrostatic combdrive-actuated micromirrors for laser-beam scanning and positioning", J. of Microelectromechanical Systems, **7**, 1, 27-37, 1998.
4. R. A. Meyer, "Optical beam steering using a multichannel lithium tantalate crystal", Appl. Opt., **11**, 3, 613-616, 1972.
5. Q. W. Song, X. M. Wang, R. Bussjager and J. Osman, "Electro-optic beam-steering device based on a lanthanum-modified lead zirconate titanate ceramic wafer", Appl. Opt., **35**, 17, 3155-3162, 1996.
6. H. Meyer, D. Riekmann, K.P. Schmidt, U. J. Schmidt, M. Rahlff, E. Schroder and W. Thust, "Design and performance of a 20-stage digital light beam deflector", Applied Optics, **11**, 8, 1732-1736, 1972.
7. N. A. Riza and S. A. Khan, "Programmable High Speed Polarization Multiplexed Optical Scanner", Optics Letters, **28**, 7, 561-563, 2003.
8. Nicholas Madamopoulos and Nabeel A. Riza, "Directly Modulated Semiconductor-Laser-Fed Photonic Delay Line with Ferroelectric Liquid Crystals", Applied Optics-IP, **37**, 8, 1407-1416 March 1998.